Long-Range Battery Electric Vehicle with Megawatt Wireless Charging

Project ID: elt262

Principal Investigator:
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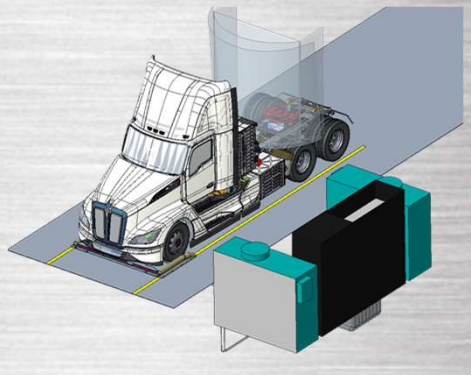
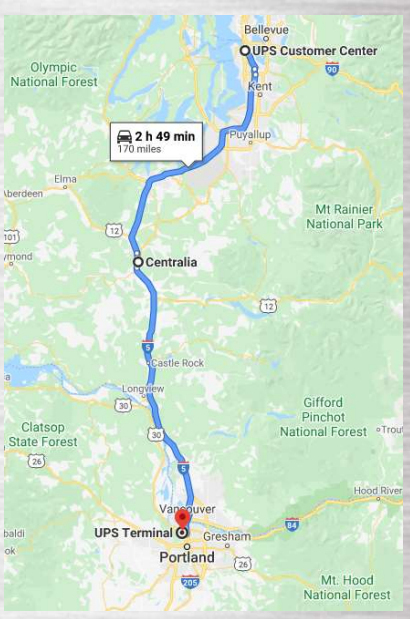
Kenworth Truck Company

DOE Vehicle Technologies Program
2022 Annual Merit Review

Presentation Agenda

- Overview
- Relevance
- Accomplishments
- Milestones
- Risk Discussion
- Project Status
- Mitigating Steps
- Prior AMR Comments & Questions
- Challenges
- Future Considerations
- Summary





Overview

Timeline
- Start Date: 1 Oct 2019
- End Date: 12 Dec 2022

Budget
- Total Project Funding: $8M
- DOE share: $5M
- Partner Cost Share: $3M

Barriers
Broad acceptance of battery-electric power for heavy trucks is hampered by:
- Range
  Typical today is 100-150 miles/day
- Re-Charge Time
  Typical today is 2-10 hours

This project will research, develop and demonstrate a Class 8 tractor and charging system capable of two-shift operation exceeding 400 miles per day. The tractor will have range of up to 200 miles and can be recharged in 30 minutes.

Project Partners
A strong and diverse team has been assembled:
- **Kenworth Truck Company** – Heavy Truck OEM
- **UPS** – Global Transportation & Logistics Fleet
- **Utah State University** – Academic Institution with Extensive Wireless Charging Expertise
- **WAVE** – Technology Startup Producing & Deploying Wireless Chargers For Heavy Vehicles
- **Seattle City Light** – Local Government-Owned Utility
- **Portland General Electric** – Local Public Utility
- **Romeo Power**– Battery System Manufacturer

Project Relevance

Impact

Heavy-Duty BEVs are struggling to gain acceptance by trucking fleets.

- Increasing the range of heavy trucks will allow fleets to more easily **integrate BEVs into daily routes**
- Reducing the charge time will allow fleets to **operate BEVs in two-shift operations**
- Minimizing battery size while maximizing daily range will allow a **smaller increase in initial purchase price** and a **smaller reduction in payload capability** compared with today's diesel powertrains
- Wireless power transfer will allow **safe and efficient** extreme fast charging with **minimal driver interaction** (no large, heavy cable to wrestle)

Objectives

- **Reduced energy use** throughout the BEV system to improve kW-h/mile
  - Baseline test vehicles were measured at an average of 2.65 kW-h/mile
  - System efficiencies in traction motor/inverter, power steering, air compressor and thermal management were explored and will be validated
- **Megawatt-rate wireless power transfer**
  - Design and demonstrate safe and efficient wireless charging at megawatt rate
  - Develop batteries and charge profile to allow adding 170+ miles of freeway range in 30 minutes

Project Level Accomplishments

Energy Storage Requirements:

- Obtained data from Seattle to Portland in range-extended electric tractor-trailer
- Included power requirements for the traction motor system plus all accessory drives such as cooling pumps and fans, power steering, air compressor, HVAC, etc.
- Conservative value for energy consumption one-way Seattle to Portland = 462 kW-h
- Selected battery system capacity of 660 kW-h
  - One-way energy use is <70% of total capacity: allows operation between 20% SOC and 90% SOC
  - Megawatt charging yields 1.5 C-rate, which is upper end for NMC cells

Magnetics & Electronics Design and Simulation:

- Significant simulation and investigation
- Design meets vehicle parameters and charging requirement
- ANSYS simulation results yield path forward for a scaled prototype pad and shield
- Development and testing plans complete
- Initial weight and space calculations complete

Milestones

Target	Description	Achieved	Responsible
Sep 2020	Design parameters for the single-stage AC-AC converter	Oct 2020	USU
Dec 2020	Preliminary infrastructure plans for charging sites	Dec 2020	USU, WAVE, UPS, SCL, PGE
Dec 2020	**Go/No-Go** Proof-of-Concept charger operation to validate the coil design, control system function, and thermal management	Mar 2021	USU
Mar 2021	Chassis layout: location of components, weight distribution, and high-voltage cable routings	Mar 2021	KW
Jun 2021	Charging site equipment design is completed	Missed	USU, WAVE, UPS, SCL, PGE
Sep 2021	Key charger components characterized and validated	Missed	USU, WAVE
Dec 2021	Grid electrical power supply in place at charging sites	Missed	SCL, PGE
Dec 2021	**Go/No-Go** Demonstrate full-scale megawatt wireless charger system in off-vehicle operation	Missed	USU, WAVE
Mar 2022	Vehicle is assembled and fully operable	Missed	KW
Jun 2022	Demonstration of the system operation with one megawatt wireless charging on site	At Risk	(All)
Sep 2022	Confirm operations exceed 400 miles per day	At Risk	(All)

KW: Kenworth

PGE: Portland General Electric

SCL: Seattle City Light

USU: Utah State University

Risk Discussion - Wireless Charger Development

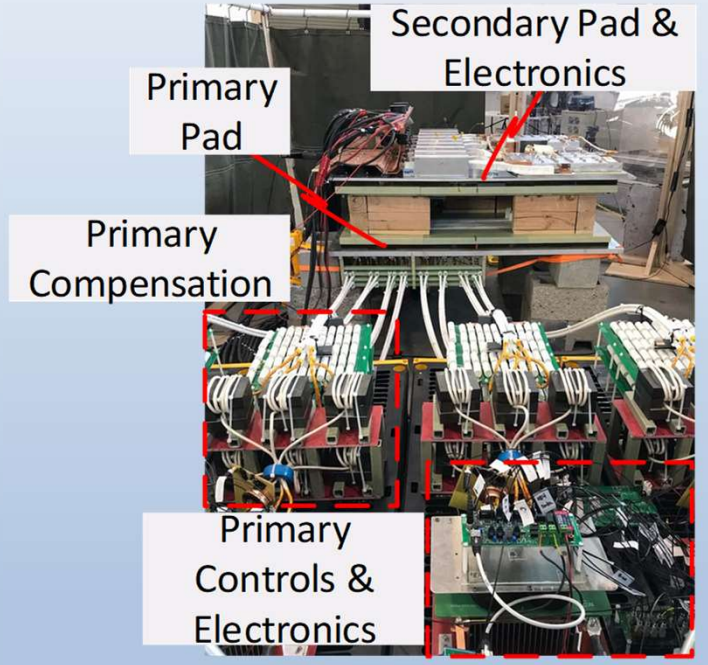
UtahStateUniversity

Accomplishments:

- Expanded prototype wireless charging pad testing from 125 kW to 850 kW
- Achieved 94.9% DC-DC efficiency at 225 mm air gap
- Completed 16kW AC-AC power electronics sub-module testing

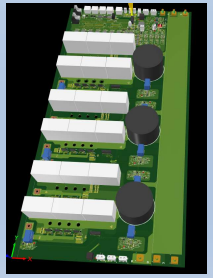
Challenges:

- Expanding power electronics to 125 kW full module test (M2.3)
- Supply chain delays to procure industrialized system components for 1 MW system
- Delayed industrialized system demonstration at 1 MW wireless power transfer (M2.5)



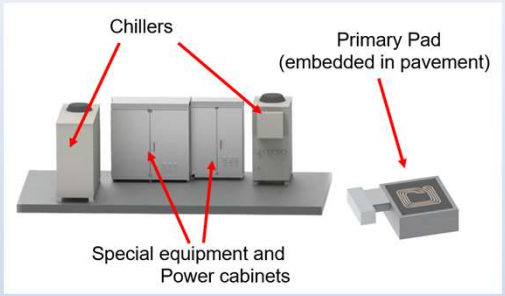
Parameter	Value
V_{out}	625 volts
I_{out}	1362 amps
Output Power	851 kW
Losses	45.5 kW
DC-DC Efficiency	94.9%

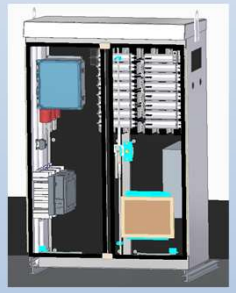
Parameter	Value
Input voltage	480 V, 3-Φ
Load	16 kW
Power factor	0.98
Line current THD	5 %

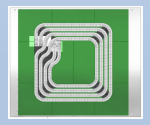


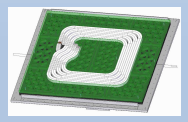
Risk Discussion - Wireless Charger Manufacture

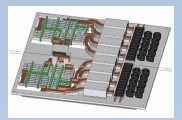
WAVE by Ideanomics











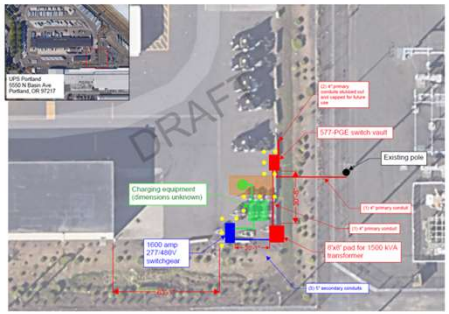
WAVE Tasks	Current Status
• Industrialization of 1 MW wireless charger system.	• Ordering long lead items ahead of time, to avoid supply chain issues and project delays. • Initiated design transition of CAD files.
• Technology Partner for 1 MW wireless charging system	• Designed and developed the primary side cold plate and coolers. • Supporting the USU team in the development of the wireless power transfer system.
• Construction of charging site infrastructure.	• Guiding the implementation partners with the electrical and civil requirements for the wireless charging system. • Shared feedback on the electrical and civil plans. • Defined the roles and responsibilities matrix for the construction.
• Commissioning and Field Certification of charging equipment.	• Initiated the certification process with UL. • Completed 1st desk review at USU with UL personnel.

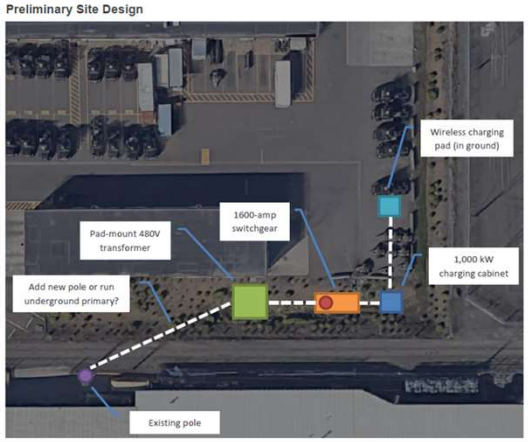
Risk Discussion - Facility Preparation

Georgetown Facility - Seattle

- Charger location selected and A&E firm engaged
- Open task is location of an analog phone line to meet regulations

Swan Island Facility





Swan Island Facility - Portland

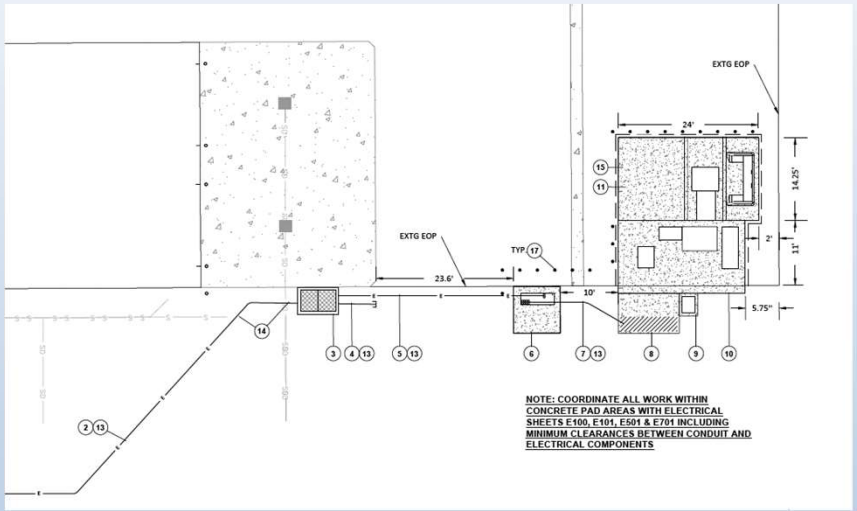
- Charger location selected and A&E firm engaged
- Open task are the review of the easements and switchgear specifications

Risk Discussion - Utility Preparation

Portland General Electric

Design Concerns:

- Agreement on use of Environmental Easement

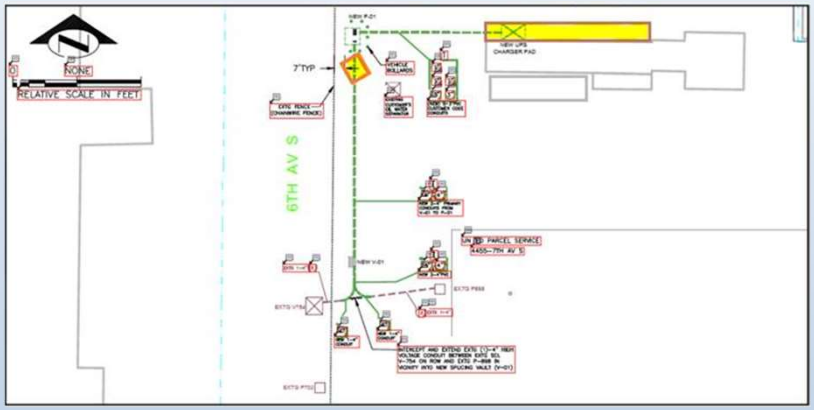


Open Issues:

- Approval required during selection of Switchgear

Risk Discussion - Utility Preparation

Seattle City Light



Design Concerns:

- None currently

Open Issues:

- Access to analog phone line to meet city regulations

Risk Discussion - High Voltage Batteries

ROMEOPOWER

Module and Pack Build:

- All modules are built and meet specifications
- Packs assembled into cradle
- Side Packs are assembled into custom container and installed on chassis
- Vehicle systems and communicate with battery management system (BMS)

Integration and Commissioning

- Communication issues list remains open
- BMS pack commands and broadcast status issues remain open
- Pack state conditions do not reflect reported BMS status

Initial SOC (%)	Total Charge Time
10	29.78 min.
15	34.52 min.
20	47.01 min.

Risk Discussion - Vehicle Build

Vehicle Summary:

- T680 Tractor: 220" WB, and 650VDC Architecture
- Projected Vehicle Weight: 27,000 lbs.

Chassis Build Status

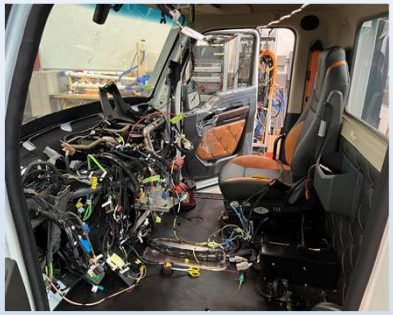
- Mechanical – Wireless Charger Secondary Pad, Cab Rework, Data Loggers to be installed and integrated.
- Electrical – data logger part changes require harness modifications
- Systems – Thermal systems to be validated, coolant flow characterizations in process, HV&LV harnesses accurate and clearance checks in process, air systems tests pending

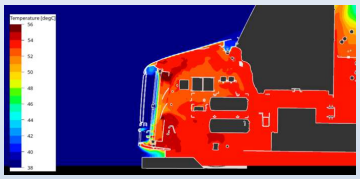
Systems Integration

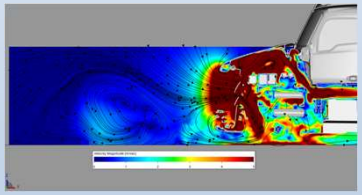
- Air systems tests pending
- CAN communication tests in process
- Hybrid ECU command control tests in process

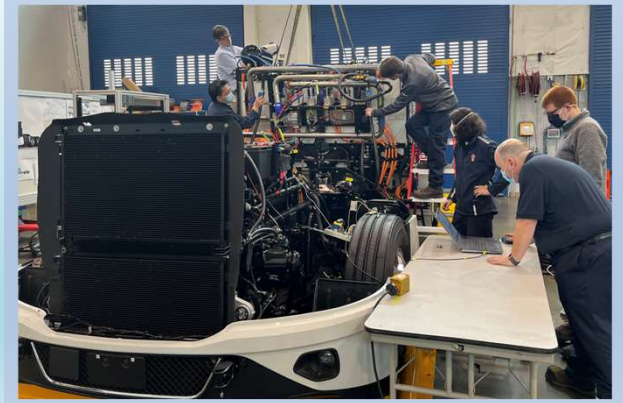
Component Issues

- HV Batteries
  - Firmware and Software tasks remain open
- Wireless Charger
  - Validation and Build behind schedule
- Electric Motor-Transmission-Converter Assembly
  - All open issues resolved, commissioning process to begin with hybrid ECU tests



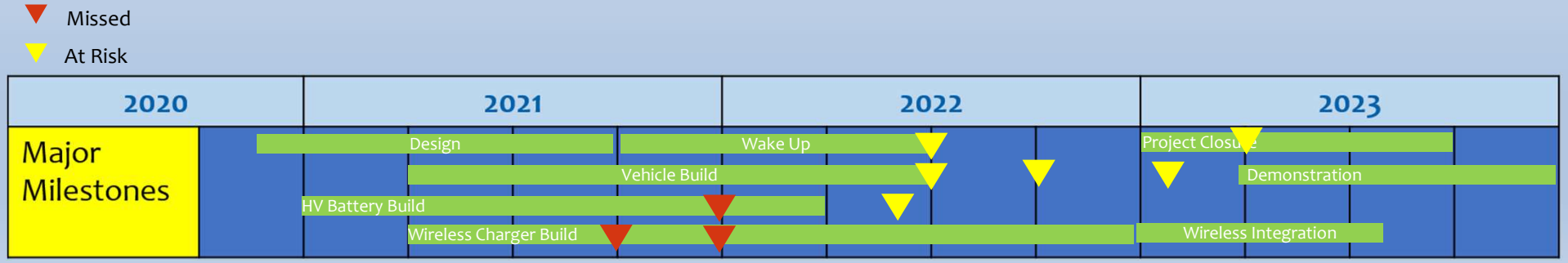






Project Status - Risk and Status

• **HV Batteries: Late due firmware and software issues**	Battery components on site, supplier sending team to Kenworth to resolve open issues.
• **Wireless Charger: M2.4 & M2.5 up to 10 months late**	Increased activity and involvement with USU and WAVE, Cooling plate for wireless charger in process at fabricator.
• **Motor-Transmission Assembly: Late due to assembly and software issues**	Unit installed in chassis, supplier on site working completing integration and commissioning
• **Chassis Layout: no issues, schedule risk from Wireless Charger**	Wireless charger design envelope maintained.
• **Controls System: at risk for wireless charger**	Kenworth controls team meeting with USU and WAVE to define controls database and signal addresses, holding schedule



Long-Range Battery Electric Vehicle with Megawatt Wireless Charging

Mitigating Steps - Project Level Discussion

Vehicle:
- Suppliers onboarded to resolve functional issues.
- Worked with UPS to begin vehicle level functional tests prior to availability of wireless charger
- Mock-up of wireless charger was designed with a high voltage plug in charger that interacts with the vehicle charging system in the same manner as the secondary pad of the wireless charger.

Wireless Charger:
- Continue active participation in joint meetings between USU and WAVE.
- Work with USU and WAVE to identify coolant plate fabrication options and reduce schedule lead time.
- Work with team to maintain clear and open communication channels for DOE reporting.

Facility:
- Designs for Seattle and Portland are complete, documentation submitted to city authorities for permit approval.
- Utility companies actively involved to support questions from permit approval groups.
- PGE, SCL and UPS aware of delays on the wireless charger and are prepared to work with the team and keep the project in motion.

Administration:
- Kenworth meets with DOE administrators on a bi-weekly basis to discuss open issues and explore alternative ideas.
- DOE is planning on supporting Kenworth's next site visit to USU and WAVE.
- Kenworth to initiate requests for resource changes to support key personnel retirement.

Prior AMR Comments/Questions

Were the charging sites on dedicated electrical services from the utilities, and if so what type of electrical tariff did the utility provide, please?

- Yes, and none currently.

What is the tolerance for parking position between plates? Are drivers able to consistently park in the right place?

- 2" total offset in one direction. A docking station to capture the vehicle over the charging pad was designed and built to ensure the vehicle is properly located.

Where are conversion losses in charging greatest and how can they be reduced? Do you know how much charging occur at 93 vs 95%

- Conversion losses are predicted to be greatest across the air gap when out of alignment. The docking station should resolve or limit this issue. Might be up to a 10% loss.

Remaining Challenges and Barriers

Technical Challenges:

- Achieving the required energy transfer in the desired time without over-voltage or over-current in the battery system remains a concern. Early testing results indicate this can be achieved when the batteries are new; aging of the batteries may slow charge times.
- Thermal management of the batteries during charging is a concern. Simulation and analysis indicates the cooling system is properly designed, but testing may reveal unexpected issues.
- Electrical noise from the charger may affect CAN communications. Steps are being taken to reduce noise and to shield communication lines, but issues may arise once the full vehicle is in operation.
- Complete charging system efficiency including ground-side cooling and vehicle-side cooling may be low enough to reduce the attractiveness of this technology.
- This project will develop a proof-of-concept system of one BEV tractor and two wireless chargers for a total cost of $10M. Can this technology be produced at affordable costs when scaled to higher volumes?

Barriers:

- Global component shortages and delivery delays remain in place due to the impacts from Covid-19.

Future Considerations

2022 FY:

- Complete the characterization of the full AC-AC converter operation, transmitter and receiver coils, Validate electric performance and finalize thermal management designs.
- Complete the design and installation plans for each charger site (Seattle and Portland), and start the permitting process.
- Finalize commercial designs of the wireless charging system.
- Complete the build of the vehicle and initiate functional testing.
- Demonstrate the charging system off-vehicle at megawatt rate.

2023 FY:

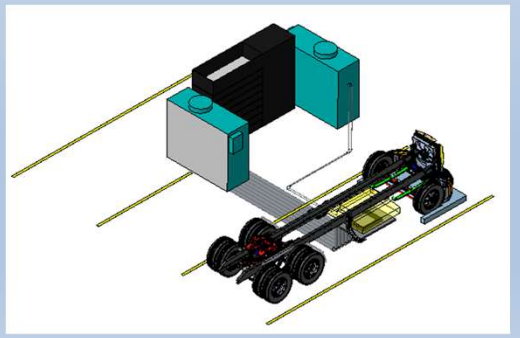
- Complete transition the charging equipment build from prototype units.
- Complete the installation of the grid power supply and charging equipment at each charging location.
- Install the charging receiver plate on the vehicle and validate power transfer to battery system.
- Complete commercial operations with the BEV tractor and wireless charging system.

Any proposed future work is subject to change based on funding levels.

In Summary

Technical Accomplishments:

- Validated through physical testing that 462 kW-h of energy can be added to a 660-kW-h battery system in 30 minutes or less.
- Validated through physical testing that multiple inverter module (125 kW) can transmit power across a 300-mm [11.8 in] air gap at 93% DC-DC efficiency.
- Completed preliminary thermal management systems for the stationary side to cool the charge plate.
- Completed air flow and coolant flow simulations for vehicle and stationary electronics cooling in worst-case scenarios.
- Completed vehicle fabrications, installation and assembly.
- Developing vehicle control system to manage on-board components and systems – 80% complete.



Thank You

Long Range Battery Electric Vehicle

with One Mega Watt Wireless Charging

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